SUPERVISORY CONTROL SYSTEM

by
Robert L. Cosgriff and Robert B. Lackey
Antenna Laboratory
Department of Electrical Engineering
The Ohio State University
Columbus 10, Ohio

INTRODUCTION

Today there are several types of adaptive control systems, systems which change as the environment of the system changes. These self adjusting systems can be divided into several categories and each category has its particular applications, its advantages and disadvantages. The various types of adaptive control systems can be classified in terms of versatility, complexity and speed of response. The major types of adaptive controls are listed and their characteristics tabulated in the table which follows. The degree of complexity is indicated by numbers from one to ten with unity indicating a simple system and 10 a complex system. Versatility is also indicated by numbers from zero to ten with zero indicating no versatility. The time necessary for the system to adapt once a change in environment is made is indicated as $n\tau$ where τ is the average time constant of the controlled system. These tabulated values are not absolute in nature but merely give an indication of system properties.

Type 1(a) system is by far the most versatile and in time it will adjust the system to a true optimum condition even if instability arises during the adjustment. Type 1(b) systems are similar to type 1(a) although not so versatile because of multiple criteria. Instability may result because of conflicting criteria.

Type 2 systems are all characterized by having a test input signal. However, the speed of response and complexity vary greatly. Type 2(c) systems will be described in a later section. Type 3 systems are the least versatile but are the simplest in construction. This type of system must be very carefully designed.

The remainder of this paper will be devoted to type 2(c) systems, one of several systems investigated in some detail at the Ohio State University Antenna Laboratory. (See references 1, 2, 3, 4, and 5 for results of other investigations.)

GENERAL DESCRIPTION OF SUPERVISORY CONTROL SYSTEM*

If values of a limited number of parameters of a linear or quasi-linear

* For other types of supervisory control systems see reference 5.

TABLE

Type	System Description	Versatility	One variable Adjusted		n variables Adjusted	
			Complexity	Time of Response	Complexity	Time of Response
1(a)	Optimizing (single criterion)	10	3	50τ	4	$50n\tau$
1(b)	Optimizing (multiple criterion)	4	6	10τ	8n	5τ
2(a)	Correlation (random)	3	10	20τ	$10n^{1.5}$	20τ
2(b)	Correlation (transient)	3	5	4τ	$5n^{1.5}$	4τ
2(c)	Correlation (sinusoidal)	3	2	τ	2n	$\frac{n+1}{2}\tau$
3	Quasi-linear design	2	1	τ	n	τ
4	Programmed	2	3	$\tau/4$	$3n^2$	$\tau/4$

system are to be controlled, a supervisory control system can be devised which measures and then adjusts the parameters of interest. The simplest method that can be used to accomplish this purpose consists of inserting a sinusoidal test signal into the system being adjusted and then sensing the output signal from this system. By proper use of phase sensitive detectors the parameter of interest can usually be detected. By comparing this parameter with a standard reference an error signal can be produced which will actuate a control motor which in turn will adjust or correct the parameter of interest. Conceptually, this type of supervisory control system differs from the conventional control system only in that a parameter of the controlled system, rather than a variable is adjusted.

EXAMPLE OF SUPERVISORY CONTROL SYSTEM

In this section a simple example of a supervisory control system is considered and test results given. See Fig. 1. Here the block labeled G(p) is considered a hypothetical aircraft where δ is elevator deflection and $\dot{\gamma}$ is the rate of change of the angle between the velocity vector and an inertial reference. The parameters A, f and k are all dependent upon the environment and velocity of the aircraft; however insofar as this paper is concerned only f will be controlled and A and k will be assumed to be constant. (The fact that these assumptions are made should not be construed as meaning that the variables A and k cannot be controlled by means of techniques described but rather that they are made to simplify the description of techniques that can be employed.) If the servo has a much faster response than the air frame the auxiliary feedback path which is to be adjusted and represented by kp will cause the effective transfer function relating x and $\dot{\gamma}$ to be modified from

$$\frac{AG_S}{p^2 + fp + k} = \frac{\dot{\gamma}}{x}$$

to

$$\frac{\dot{\gamma}}{x} = \frac{AG_S}{p^2 + (f + k\,G_S A)\,p + k}$$

Here G_S is the static gain of the servo.

Adding the test signal to the input of the servo system will cause $\dot{\gamma}$ to have a sinusoidal signal component of the form

$$\frac{AG_S \quad C}{\left[(k - w_o^2)^2 + w_o^2\,(f + k\,G_S A)^2\right]^{1/2}} \cos\,(w_O t + \theta)$$

which will have a quadrature component given by

$$\frac{AG_S C \ (f + k G_S A) \ w_o \sin w_o t}{(k - w_o^2)^2 + (f + k G_S A)^2 \ w_o^2}.$$

If w_o^2 is equal to k, this latter expression simplifies to

$$\frac{AG_S C}{(f + k G_S A) \ w_o} \sin w_o t .$$

This particular component of $\dot{\gamma}$ can be separated from $\dot{\gamma}$ by means of a phase sensitive detector shown in Fig. 1. Subtracting the output of this detector from the reference signal yields an error signal which actuates the motor and thereby adjusts k. At the steady state condition

$$\frac{AG_S C}{(f + k G_S A) \ w_o} = k_o$$

The foregoing system has been simulated by means of an analogue computer and the response is indicated in Fig. 2. Rapid changes were made in f adjusting it from one constant value to another and the variable $f + k G_S A$ plotted. Note that $f + k G_S A$ returns to a constant value in about one period of the test signal, namely in time t_d given by

$$t_d = \frac{2\pi}{w_o}$$

GENERAL CONSIDERATIONS

In design of high speed supervisory control systems of the type described, many practical considerations must be taken into account. First, if the output of the detector is amplified and directly excites the control motor spurious unstable modes may be encountered in that k will have a periodic component and the overall system reduces to a linear system with time varying coefficients. Such systems can have unexpected unstable modes of operation.

The choice of w_o is of importance for two reasons. First, the upper limit for the speed of response is generally proportional to w_o. Thus for high speed operation w_o must be large.

Second, if w_o is chosen near the resonant frequency $\sqrt{k}$, noise, both internal and aerodynamic, may cause k to have a noise component larger than desired. For this reason it is generally desirable for w_o to be somewhat larger than $\sqrt{k}$.

If all three parameters, A, f and k are to be controlled at least two test signals must be employed. In general the number of test signals required is equal to one half the number of variables to be adjusted.

Finally, one is interested in the complexity of the equipment required for the supervisory control unit. Generally this equipment is far less complex than is expected particularly if other components, normally installed can be used for sensory purposes.

1. Cosgriff, R. L., " A Study of Nonlinear Servomechanisms" , Ohio State University Antenna Laboratory report AF 18(600)-88, E. O. 112-61 SR-6f4, Chapter 4, 1953.

2. Cosgriff, R. L., " Stabilization of Nonlinear Feedback Control Systems" , Proc. IRE, Vol. 41, pp. 382-385, March 1953.

3. Cosgriff, R. L., Nonlinear Control Systems, McGraw-Hill Book Co., Inc., New York, 1958, Chapter 4.

4. Cosgriff, R. L., Emerling, R. A., " Optimizing Control Systems" , Applications and Industry (AIEE publication) No. 35, March 1958, pp. 13-16.

5. Cosgriff, R. L., Nonlinear Control Systems, ibid, Chapter II.

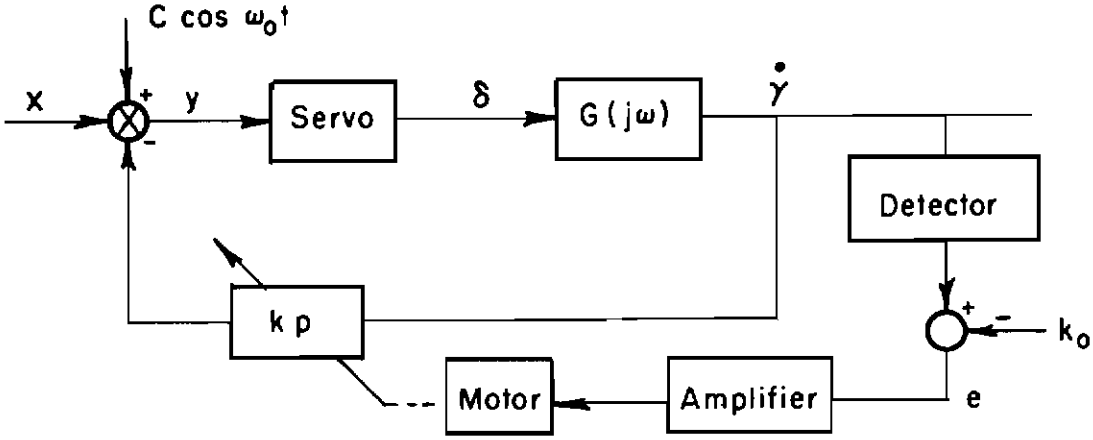

Fig. 1. Supervisory Control System for Hypothetical Aircraft.

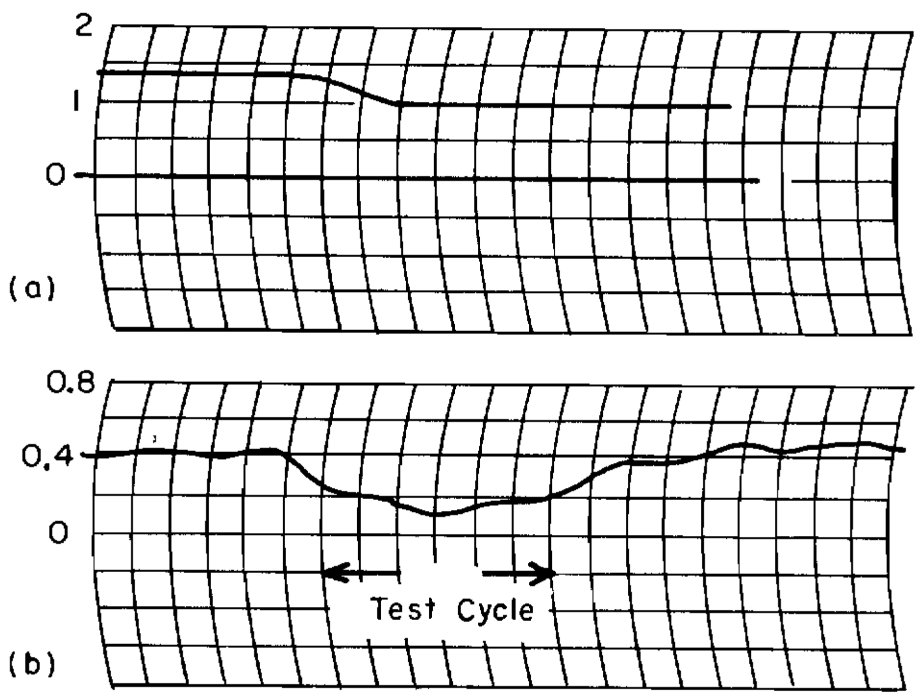

Fig. 2. Typical Response.
(a) Natural damping factor
(b) Total damping factor.